Accurate Representation Of Arbitrary Depth Source Terms In Coastal Wave Prediction Models

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LONG-TERM GOALS

The principal goal of this project is to improve our understanding of the interactions governing the spatial and temporal evolution of surface waves in arbitrary depths. This will be accomplished through the Shoaling Waves large-scale field experiment (SHOWEX) and coordinated wave modeling improvements through the Advanced Wave Prediction Program (AWPP). The results of these studies will fill Naval Operational wave forecasting needs for accurate and computationally efficient estimates of the nonlinear wave-wave interaction (S_{nl}) source term for arbitrary depths.

SCIENTIFIC OBJECTIVES

The principal objective of this project is to investigate via numerical means the source term balance in shoaling waves, test newly constructed exact S_{nl} solutions, develop an improved Discrete Interaction Approximation (DIA, Hasselmann et al 1985, Komen et al 1994), test the approximation method, and ultimately implement this approximation in existing Naval Operational Wave Forecasting methodologies.

APPROACH

The action balance equation has two distinct parts to be solved: spatial changes in the spectrum (i.e. propagation shoaling and refraction) and the temporal changes described by the source terms: atmospheric input (S_{in}), nonlinear wave-wave interaction (S_{nl}), dissipation due to whitecapping (S_{ds}), and wave-bottom effects (S_{wb}). The Shoaling Waves field experiment (SHOWEX) will attempt to directly measure the atmospheric input, whitecapping, and the effects of wave-bottom interactions. The nonlinear interactions will be directly calculated in this study using the work of Resio et al (1999) for arbitrary depths. Assessment of the dissipation measurements will be indirectly validated from the source term balance, (again computed from all mechanisms). Exact solutions (using the full dispersion relationship) as well as approximations derived from Herterich and Hasselmann (1980) scaled to deep water S_{nl} (Resio and Perrie 1991) will be implemented in 3rd generation wave modeling technologies leading to an improved Discrete Interaction Approximation (DIA) presently used in operational wave models (Komen et al 1994). Data obtained from SHOWEX will be used for the source term balance adjusting the formulations for S_{in}, S_{ds}, and S_{wb} derived from the data.

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WORK COMPLETED

Academic tests of the arbitrary depth Resio-Tracy (RT) exact S_{nl} method (Resio et al 1999) continued. These results were inter-compared to Hasselmann and Hasselmann (1981), the RIA method (Lin and Perrie 1997) and existing DIA derived from WAM. This was to assure a consistency between exact solution methods as well as to determine the strengths/weaknesses in the DIA methodology. In all cases the RT method produced consistent results to that of Hasselmann and Hasselmann (1981) for a wide variety of input spectra (including directional shear cases) and differing water depths.

The AWPP S_{nl} group (Resio, Jensen, vanVledder, Zakharov, and Herbers) met two times during the year, to discuss on-going activities, plan the next phase of testing, and future collaborative efforts. The consensus of the group was to focus on the RT method for exact solutions, direct implementation in 3rd generation wave modeling technologies, WAM (Jensen and Resio), SWAN (vanVledder), pursue alternate approximations, such as the diffusion approximation (Zakharov), and higher order approximations to the existing DIA (vanVledder). Implementation of the exact RT solution method into WAM assumes accurate arbitrary depth S_{nl} results can be obtained using deep water calculations and scaled via Herterich and Hasselmann (1980). Although the computational requirements may exceed thresholds sought (e.g. comparable to that of DIA), applications for source term balance in SHOWEX can be performed, as well as establishing the framework for subsequent implementation of the newly constructed approximation for S_{nl}.

Pursuing a replacement for the DIA in existing Navy operational wave modeling technologies has focused on reducing the computational load required for the exact RT method. Three methods were pursued, the first was to restrict the integration to areas of the integral where the coupling coefficients are large. This in effect would decrease the number of points describing a loci, representing each quadruplet interaction, and thus decrease computation time. The second approach takes advantage of new architecture and accessible tools for scalable platforms now used by the Naval operational forecasting centers. These methods dynamically distribute the work to N CPU•s, reducing wall-clock time. The third focused effort involves synthesis of a large number of exact RT simulations for various input spectra and differing water depth configurations to determine if a statistically coherent form of S_{nl} can be described in frequency and direction space using spectral parameters and scaling relationships.

RESULTS

The most computational intensive portion of all exact solution methods is in the calculation of the coupling coefficients required in the Boltzmann integrals that estimate the nonlinear wave-wave interaction. If one selectively chooses points on the loci corresponding to large coupling coefficients the computational load would be significantly reduced. This concept was applied to the RT method for a large number of input spectra, differing water depths and compared to the exact solutions. It was found that results in the area of the spectral peak (positive low frequency lobe) could be scaled but the estimates in the region above the spectral peak would not produce the negative and high frequency positive lobes, a signature of the exact S_{nl} results. Calculations involving all coupling coefficients greater than 90 percent (50 and 75 percent were also tested) of the maximum coupling coefficient for each loci produced results that were approximately a factor of two lower than the exact calculations. These results indicate that a scaling system using only sections of the loci where the coupling coefficients are large does not provide a correct representation of the integral.

The second focused effort involved the use of newly developed computational tools permitting parallelization of the RT solution method. Reducing the run times for a source term integration is critical for application of the exact solution in an operational wave model. These tools (e.g. OpenMP and re-coding) improved the actual run times by a factor of 8, using eight processors. Unfortunately the scalability of the RT method is limited, because of the size of the integration. One needs an additional factor of 10 speed-up to be competitive with present DIA solution methods. Thus, alternatives to the integration methods are being pursued.

The third focused effort involves the synthesis of many runs using the RT method for various input spectra, and differing water depth to generate a parametric form of the S_{nl} that can be scaled to spectral parameters. During these tests, it was found that the one-dimensional S_{nl} (as a function of frequency) is independent of any linear directional shear applied to the input spectrum. In addition it appears (Figure 1) there is a tractable solution to the location of the positive and negative lobes of S_{nl} in frequency, direction space. More testing will be performed to develop these sets of parameterizations.

IMPACT

One views the continental shelf as an environment that significantly alters the deep water directional wave spectrum. The source/sink terms impact their control over changes in the directional spectrum while bathymetric effects attempt to steer the energy dictated by local water depth gradients. What has been found thus far is that the arbitrary depth RT S_{nl} results emulate historical, baseline results, and provide a significant improvement in computational requirements never before realized. Despite being nearly one order of magnitude slower than the DIA methods, the net gains in the correct estimation of S_{nl} as well as the basis to make significant strides in replacing the DIA with a far more accurate approximation is now obtainable.

TRANSITIONS

The results derived from this study will be further developed leading toward a 1-D model (vanVledder leads), a complete set of source terms as well as the effects due to changing water depths. This model will be used to calculate near real time source term balances during SHOWEX. The RT methods will be incorporated in the architecture for research purposes and evaluated for deep and arbitrary depths. Ultimately, the results from these projects will yield a newly formulated approximation to S_{nl} to be ingested in Naval Operational Wave Forecasting Systems for better approximations of wave conditions over the continental shelf.

RELATED PROJECTS

Listed below are various projects that are directly related to the SHOWEX and the AWPP.

1. Headquarters, U.S. Army Corps of Engineers: •Modeling the Evolution of Directional Wave Spectra in Arbitrary Water Depths.• Development, investigation, validation of modeling technologies and transition to the U.S. Army Corps of Engineers district, division offices and in-house Coastal and Hydraulics Laboratory staff for use in the estimation of wave condition in the nearshore domain.

2. Department of Defense HPC Software Support Initiative (CHSSI) in Climate-Weather-Ocean. Migration of WAM to scalable computational environments.

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PUBLICATIONS

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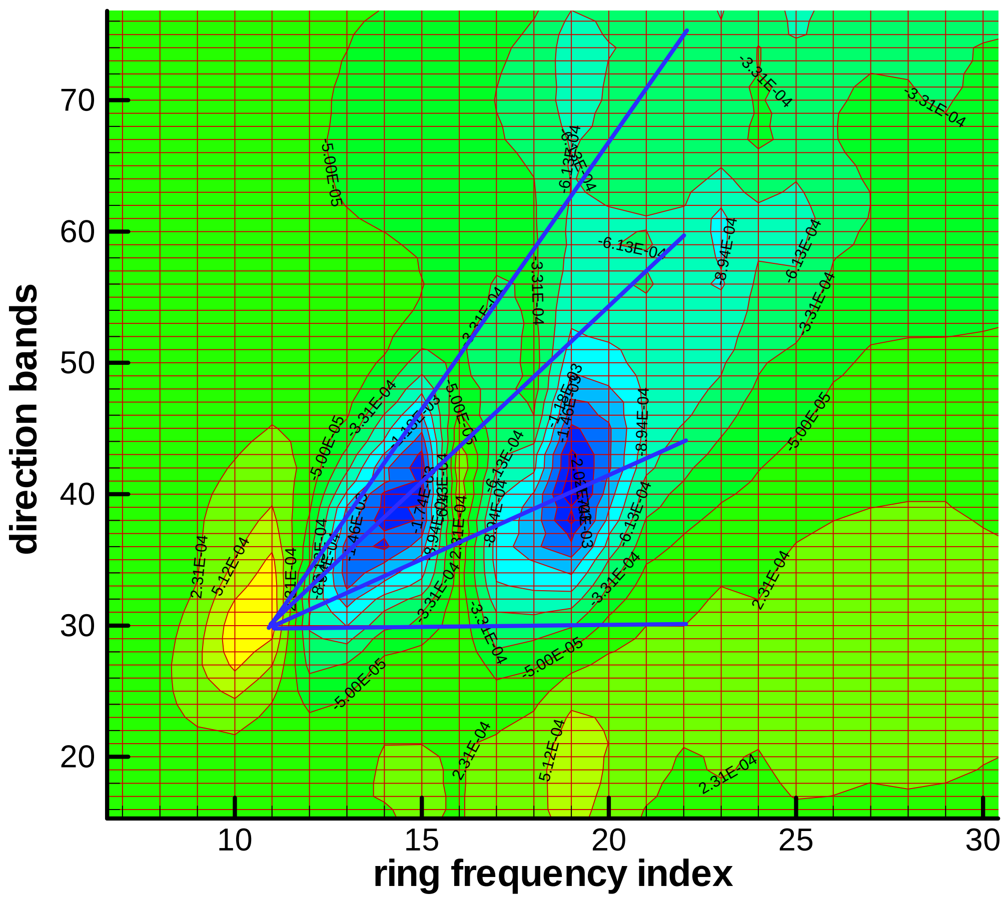

Figure 1. Contour plot of the resulting non-linear source function for a spectrum with directional shear (f_m=0.15 Hz centered at –90 degrees and 2*f_m centered at +45 degrees, f_m at x=11). Contour values show de/dt. The x-axis represents the frequency input bands and the y-axis shows a portion of the 121 direction bands with 1 corresponding to –180 degrees at 3 degree increments.